Speculative optimizations in the Graal Just-In-Time compiler

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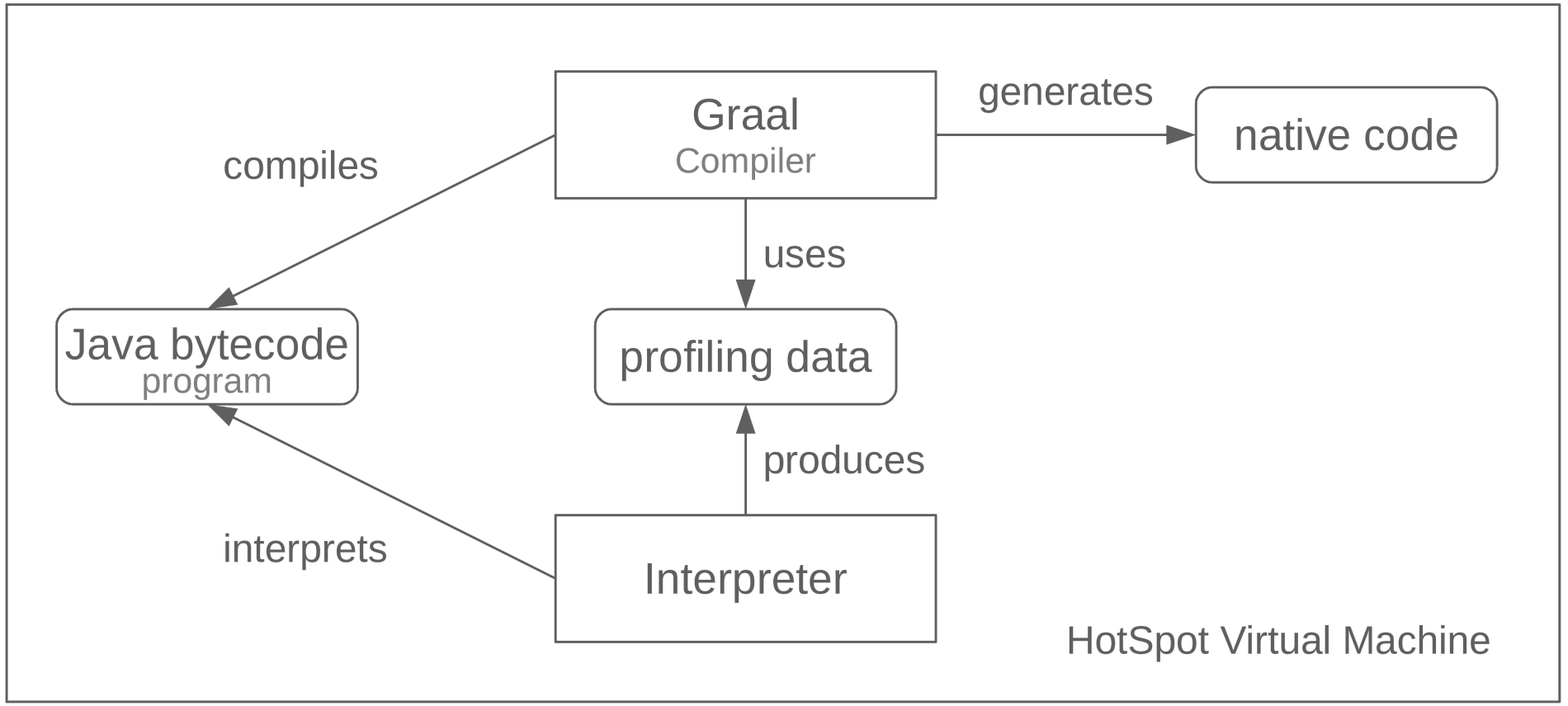
Context



Profiling

- Branches with counts (if, switches, …)
- Types with counts (virtual calls, checkcasts, …)
- Exceptions at calls

Motivating Examples

```
if (unlikely()) {
  // complex
} else {
  // simple
}
```

Motivating Examples

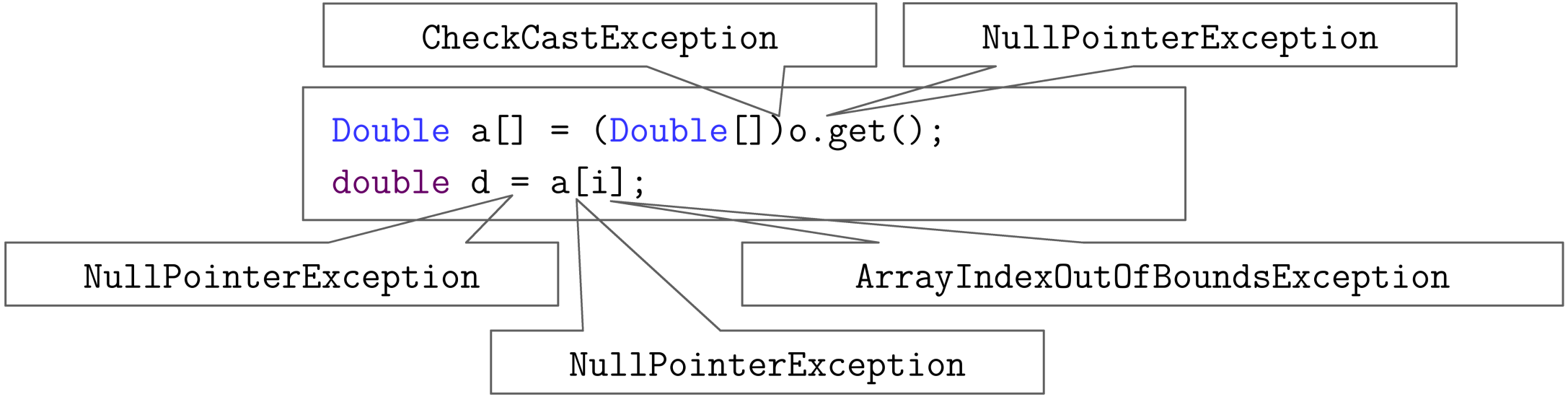
```
if (a instanceof Foo) {
  // ...
}
```

Motivating Examples

```
Foo f = getFoo();
if(f.get()) {
  // complex
} else {
  // simple
}
```

```
class Foo {
  public boolean get()
{
    return false;
  }
}
```

Motivating Examples



Speculative Optimizations

An optimization is **speculative** if it relies hypotheses that are not verified during compilation.

Guards

Guards check conditions during execution and **deoptimize** on failure.

Deoptimization exits the compiled code and resumes execution in the interpreter.

Assumptions

Assumptions are speculative invariants maintained by the VM.

When invalidated, the VM pauses execution and **deoptimizes** all code that relied on this assumption.

Revisiting the Examples

```
if (unlikely()) {
  // complex
} else {
  // simple
}
```

```
if (unlikely()) {
  deoptimize;
}
// simple
```

Revisiting the Examples

```
if (unlikely()) {
  // complex
  f = new Foo();
} else {
  // simple
  f = new Bar();
}
```

```
if (unlikely()) {
  deoptimize;
}
// simple
f = new Bar();
```

Revisiting the Examples

```
if (a.getClass() == Foo.class) {
  // ...
}
```

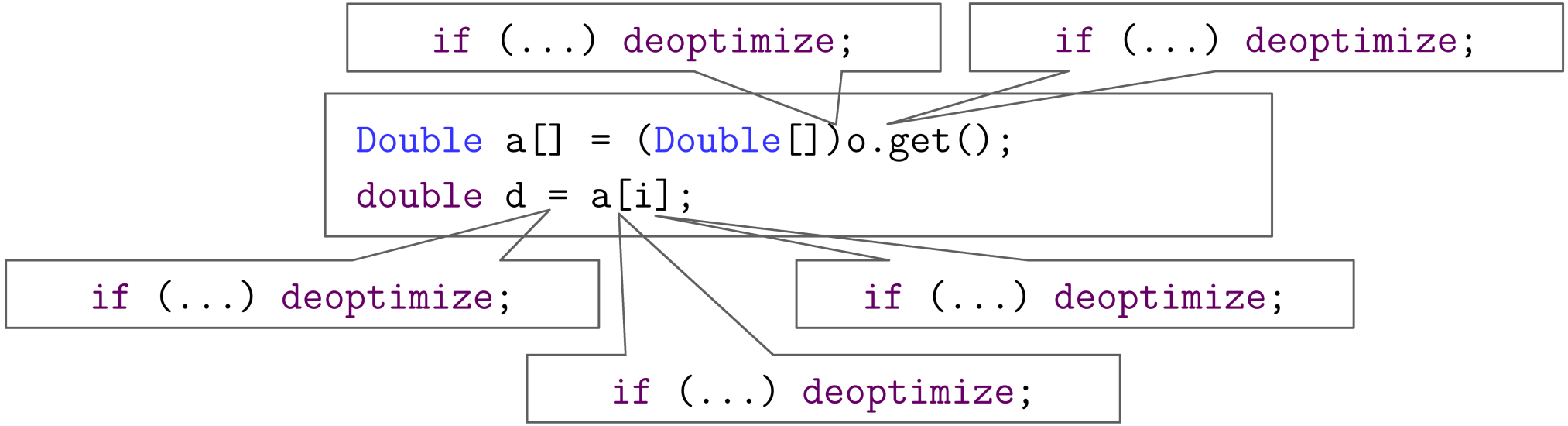
Revisiting the Examples

```
Foo f = getFoo();
if(f.get()) {
  // complex
} else {
  // simple
}
```

```
Foo f = get();
if(f.getClass() != Bar.class) {
  deoptimize;
}
// simple
```

```
class Bar {
  public boolean get()
{
    return false;
  }
}
```

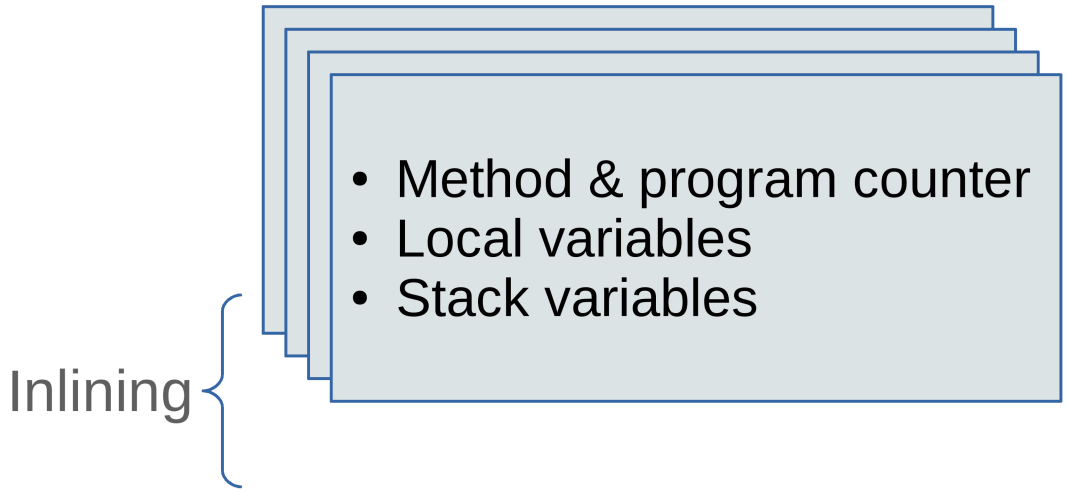
Revisiting the Examples



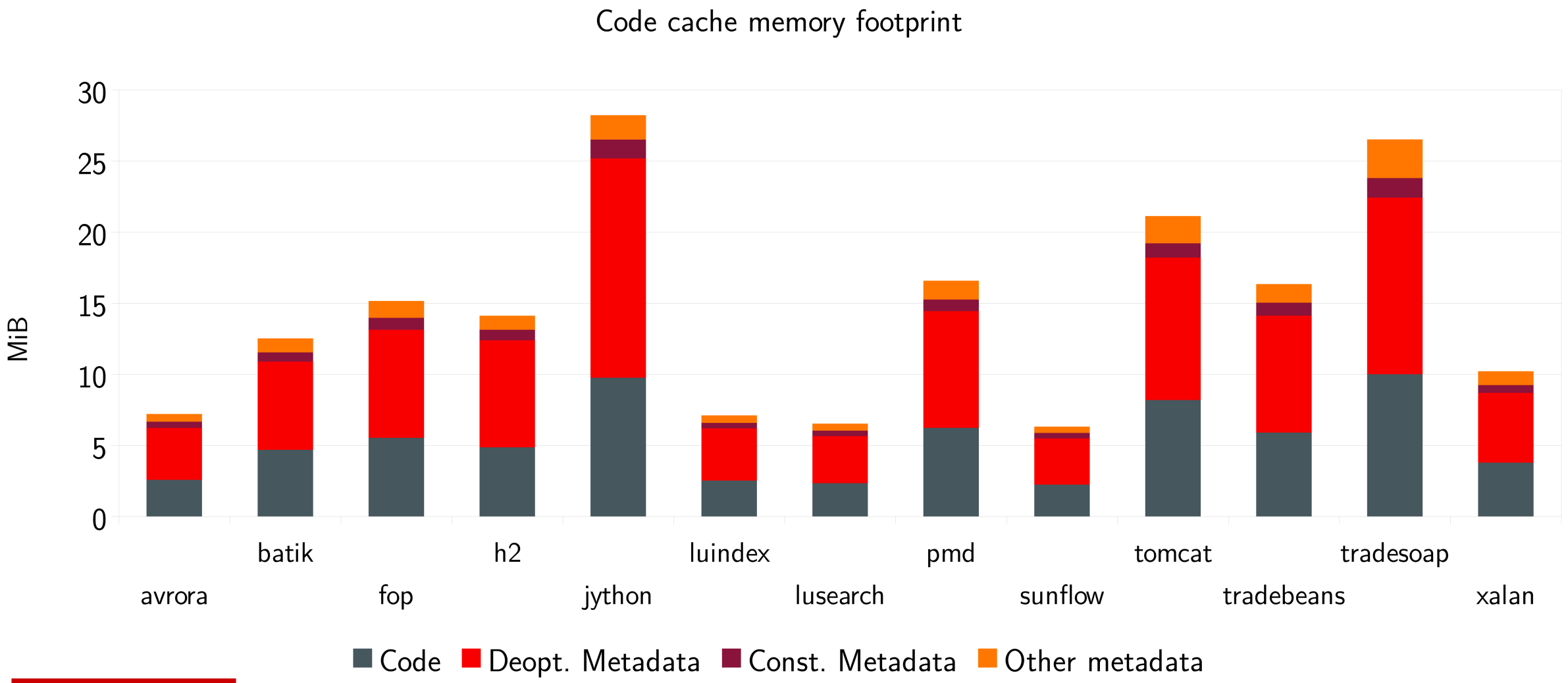
Speculation: Run-time Costs

Guards are **run-time** checks executed by the compiled code

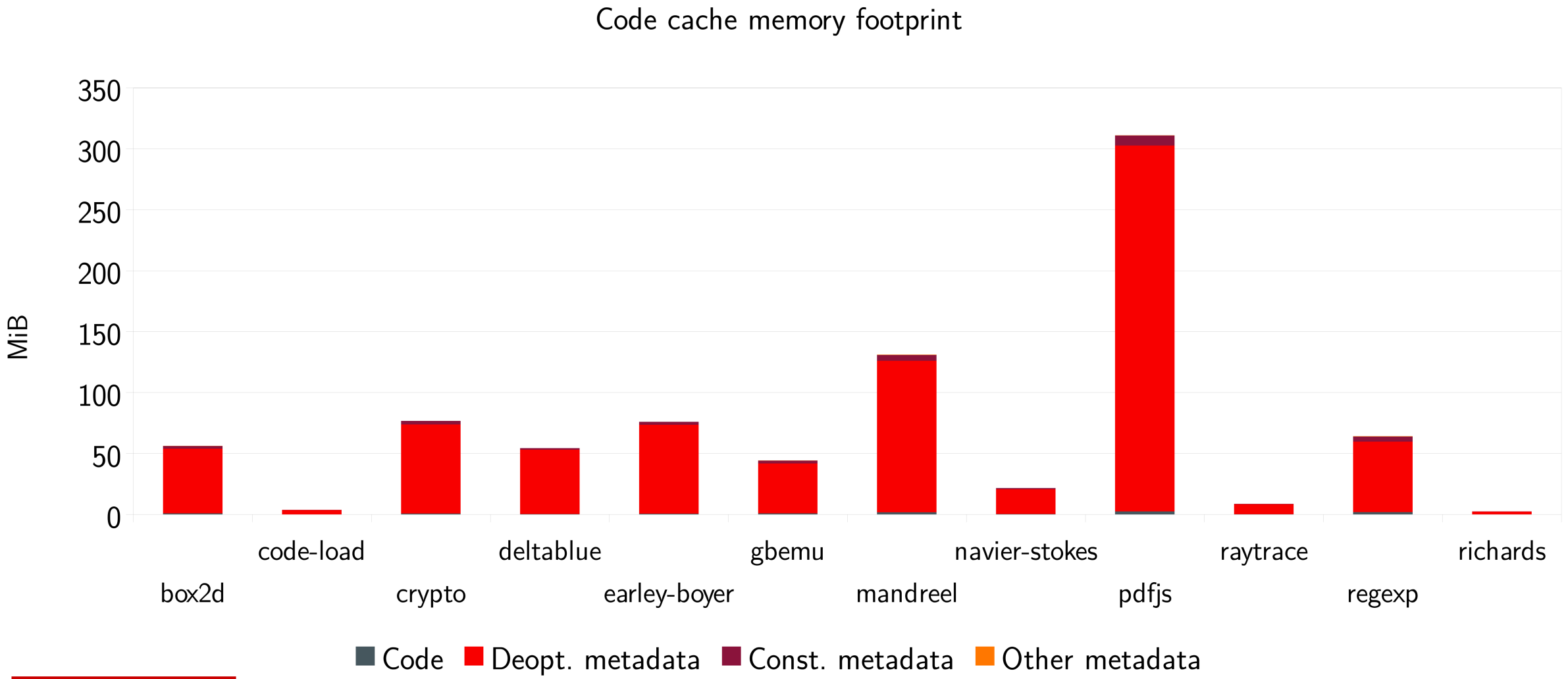
Speculation: Memory Costs



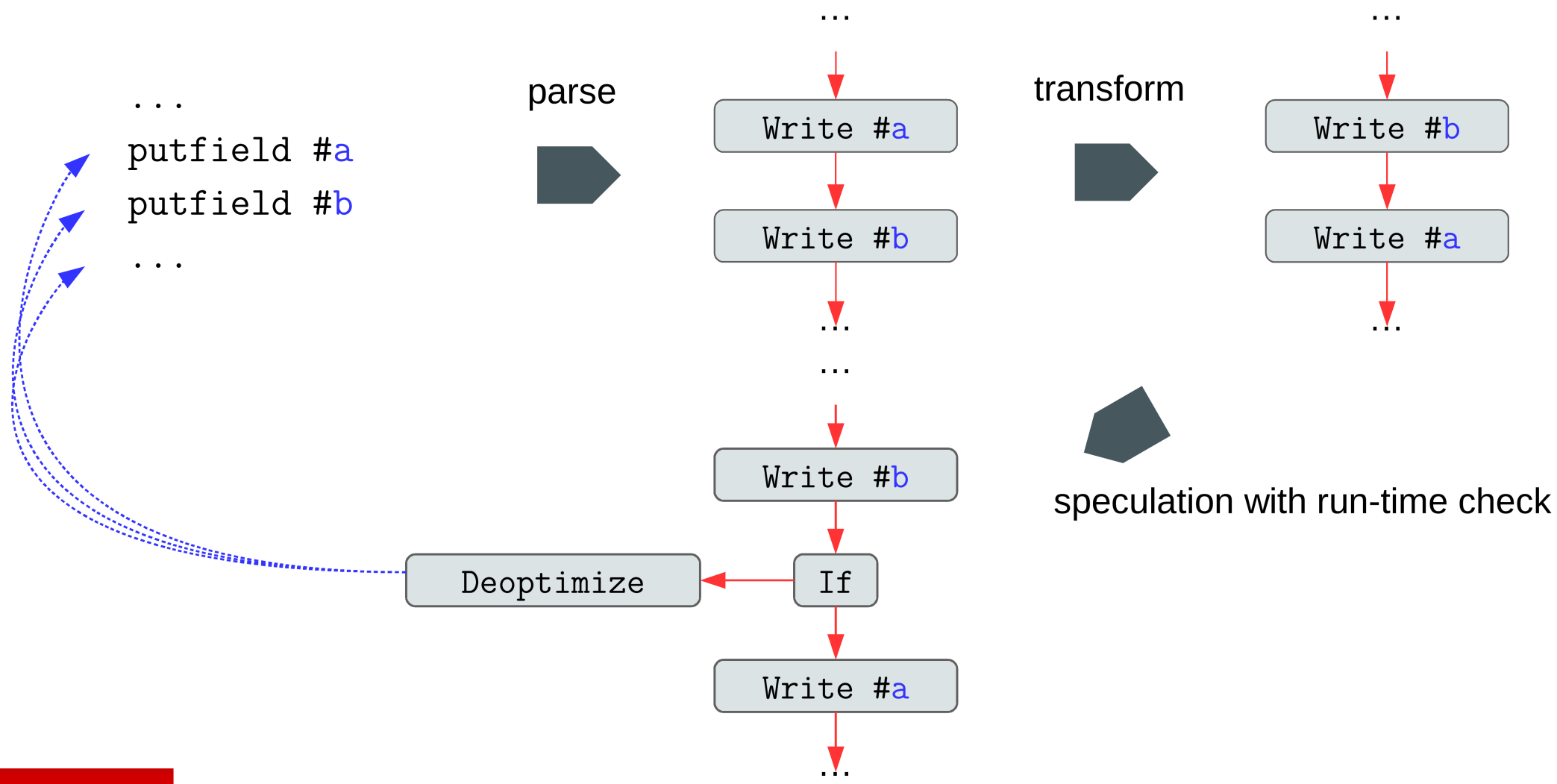
Speculation: Memory Costs



Speculation: Memory Costs



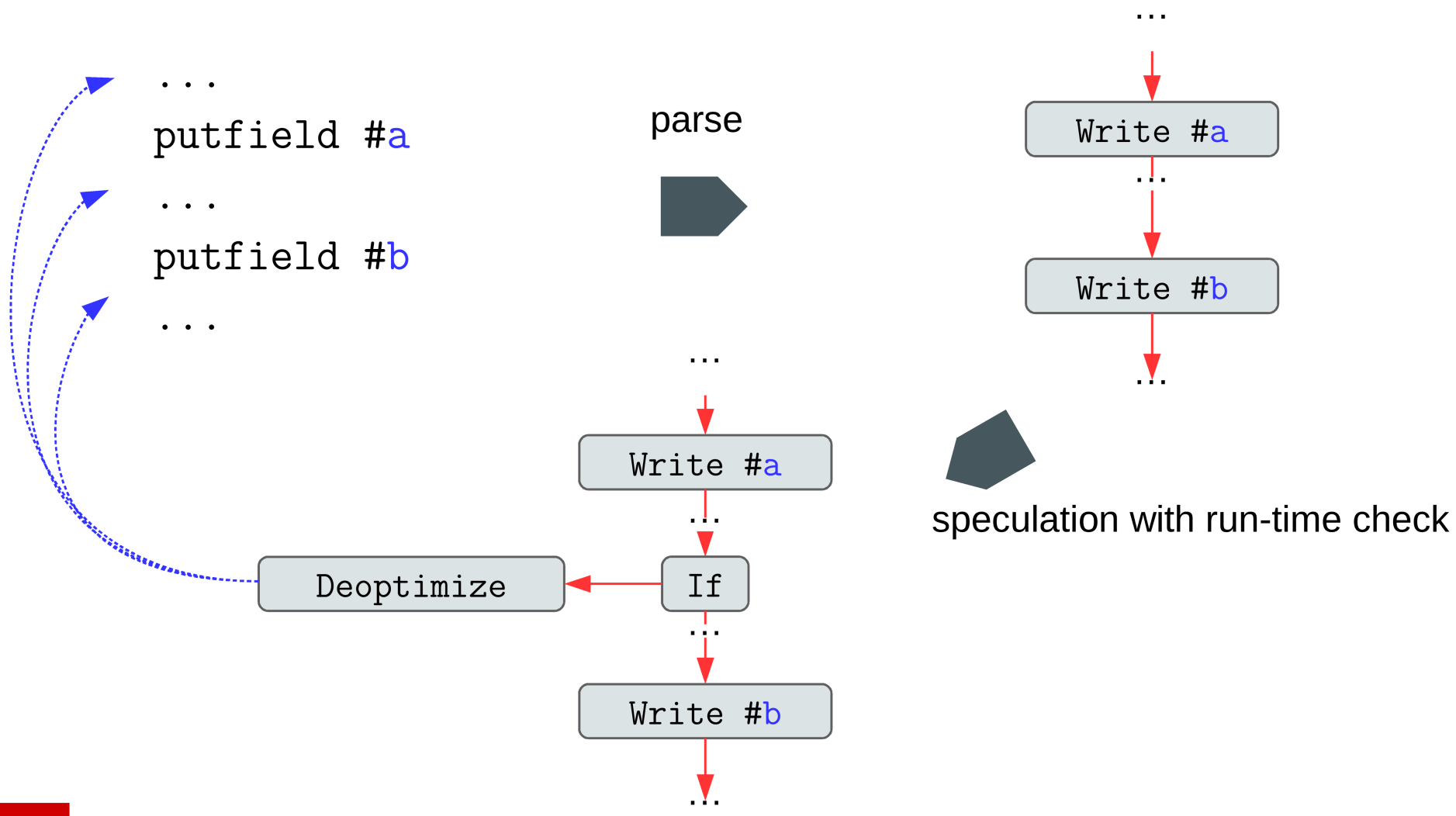
Deoptimization Targets



Deoptimization Targets

Two side-effecting instruction can only be reordered if there is no deoptimizing instruction between them.

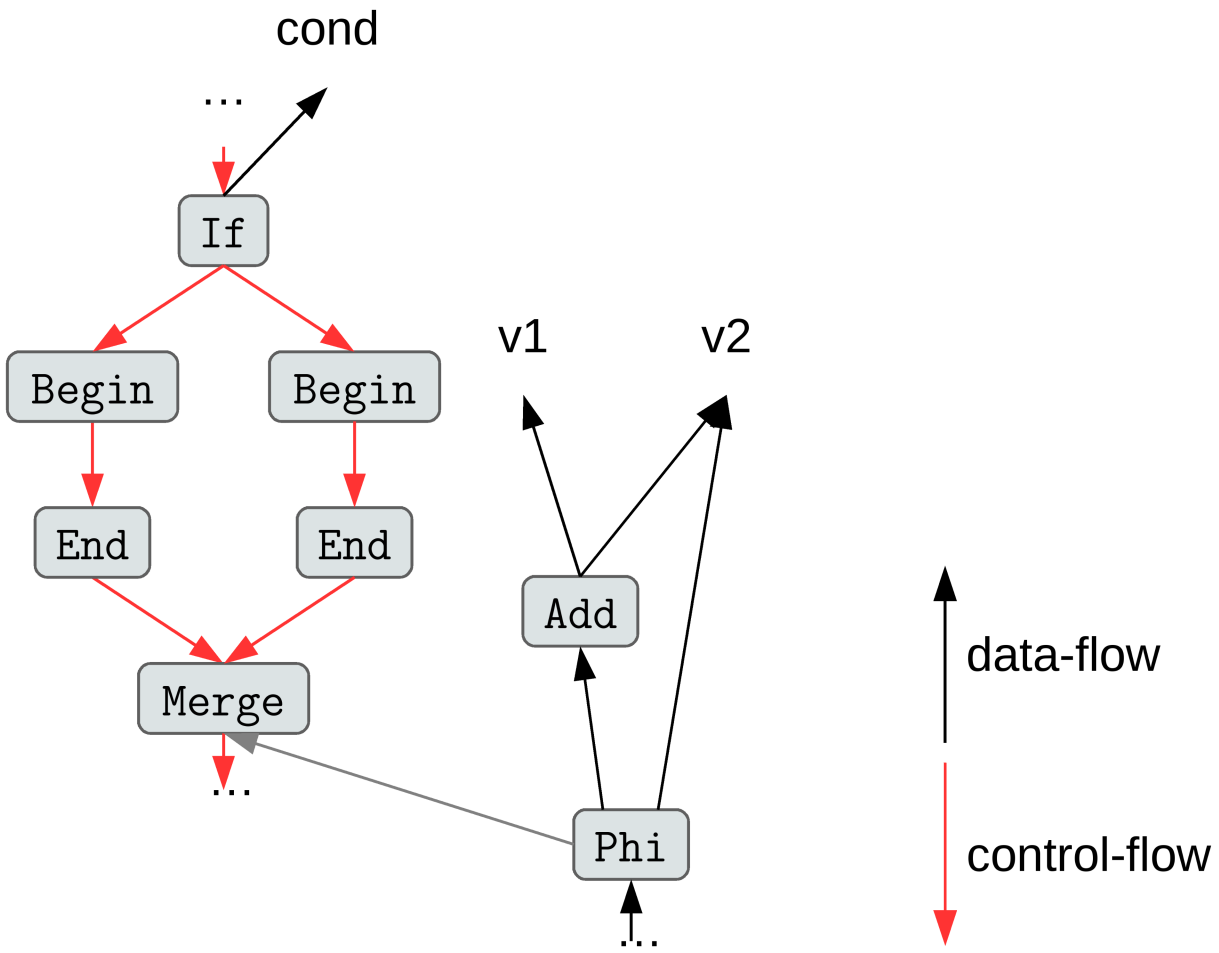
Deoptimization Targets



Deoptimization Targets

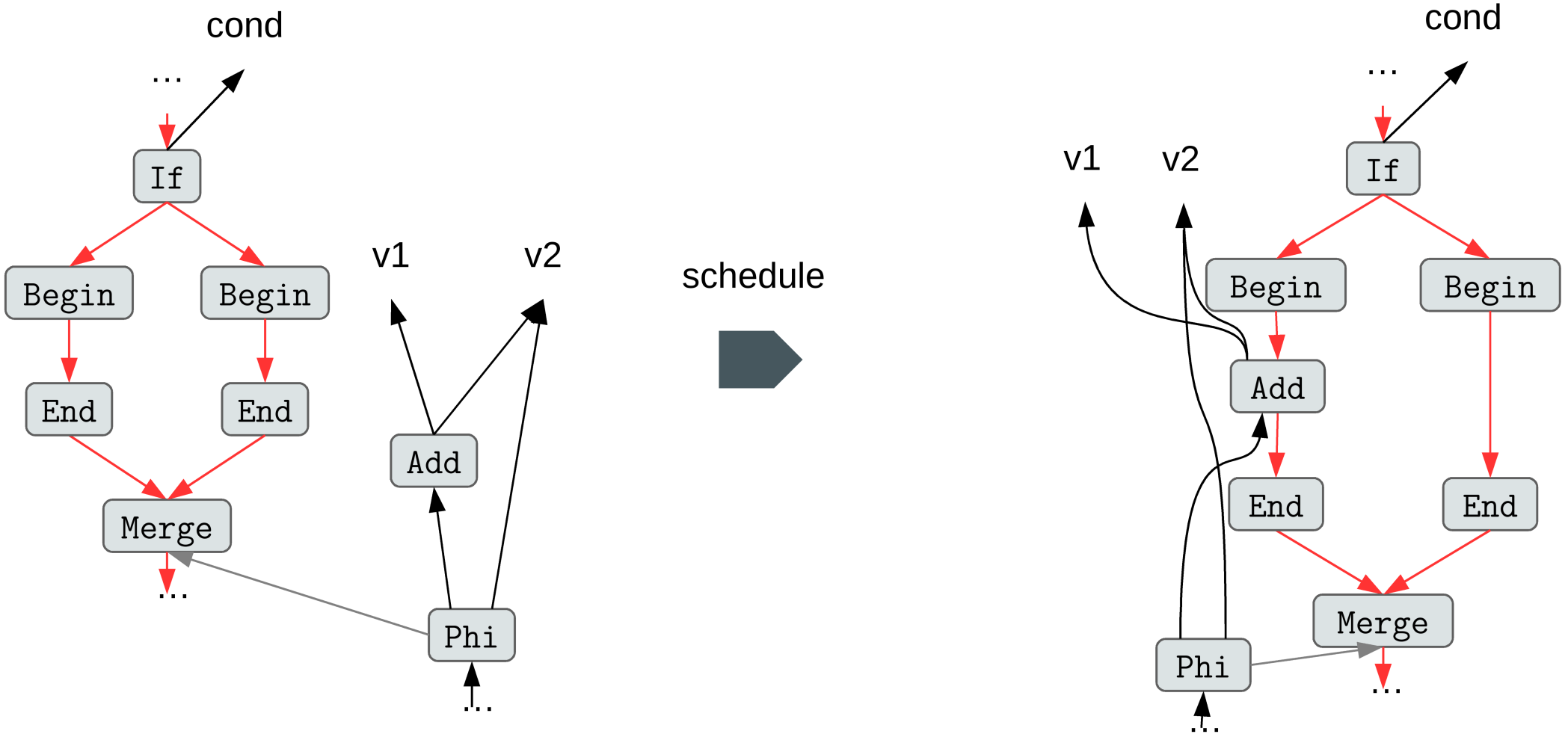
If there is a deoptimizing instruction between two side-effecting instructions, the deoptimization target must be between the corresponding side-effecting bytecodes.

Intermediate Representation

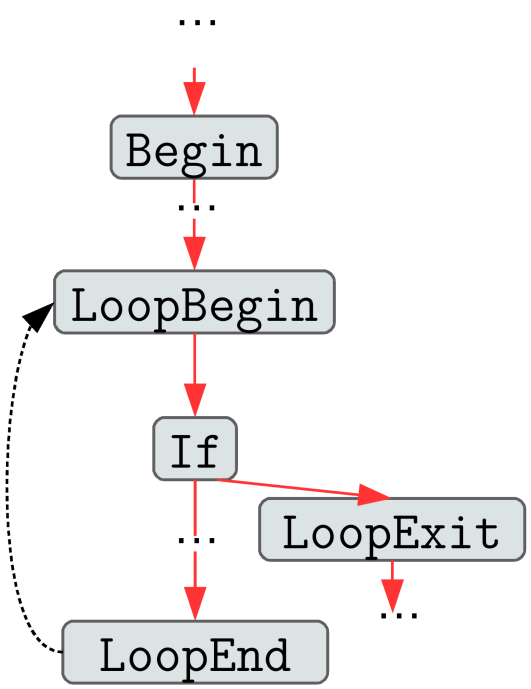



```
if (cond) {
  foo = v1 + v2;
} else {
  foo = v2;
}
```

Intermediate Representation

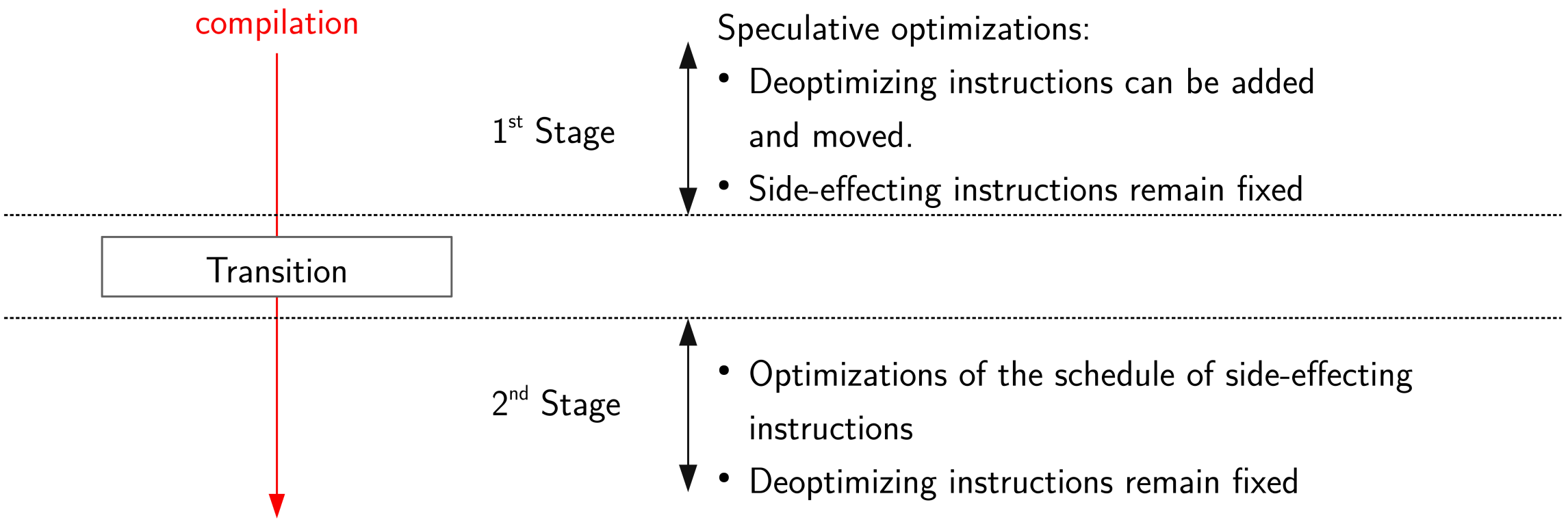


Intermediate Representation

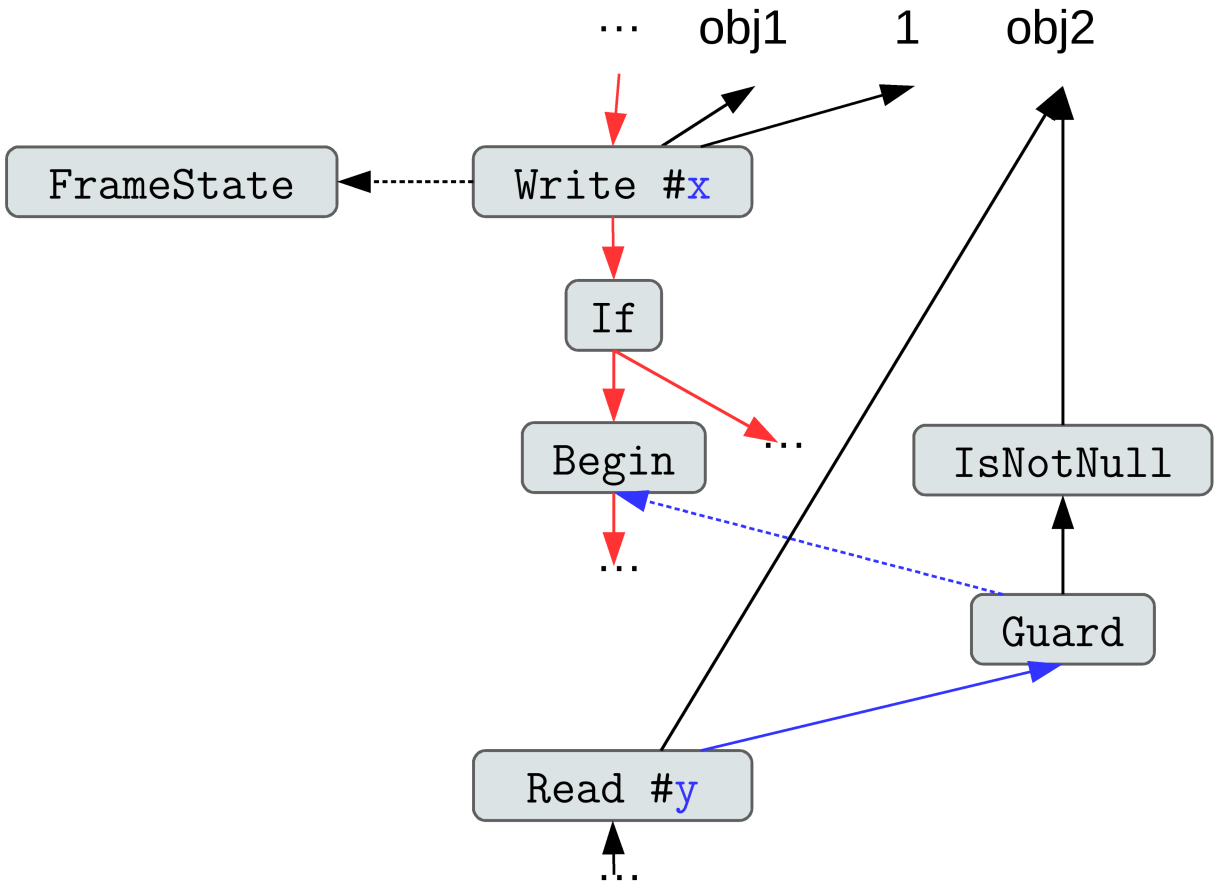


- No irreducible control-flow
- Explicit loop structure

Optimization Stages

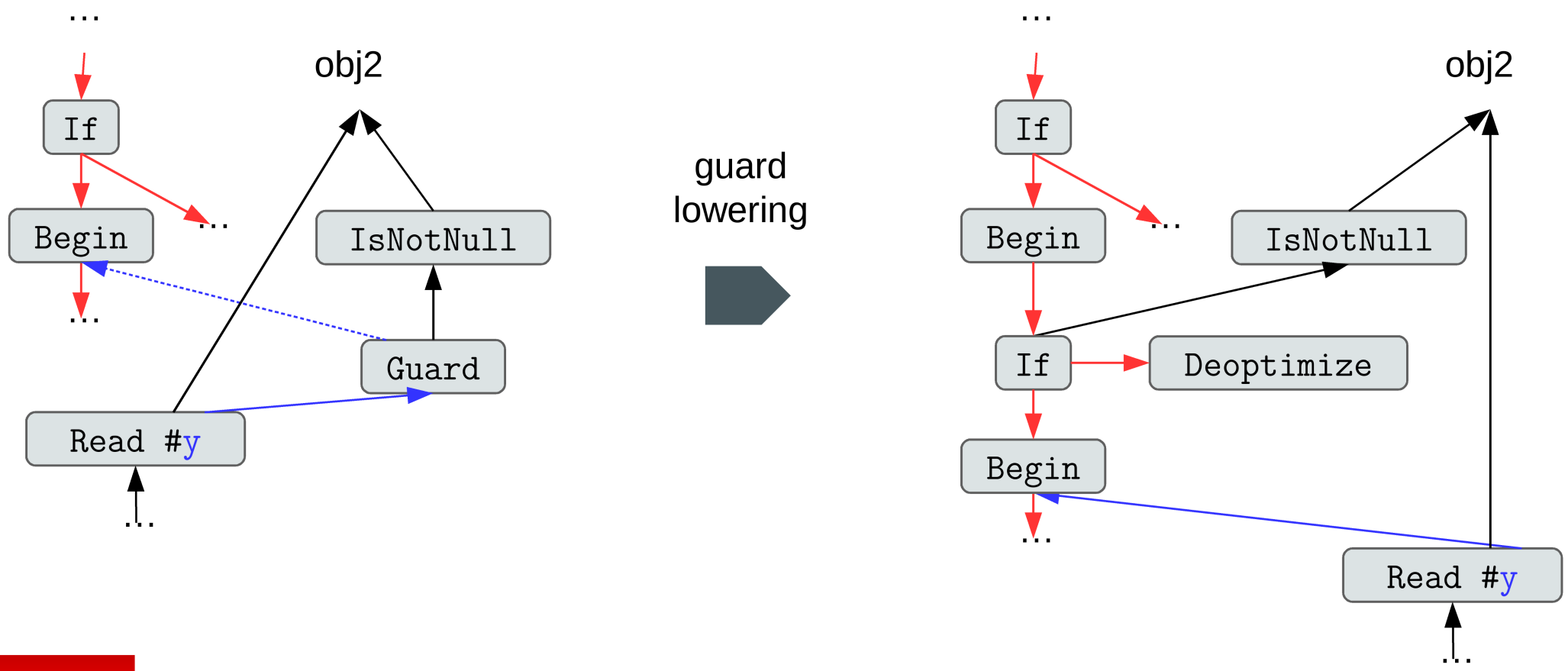


Optimization Stages: 1st Stage

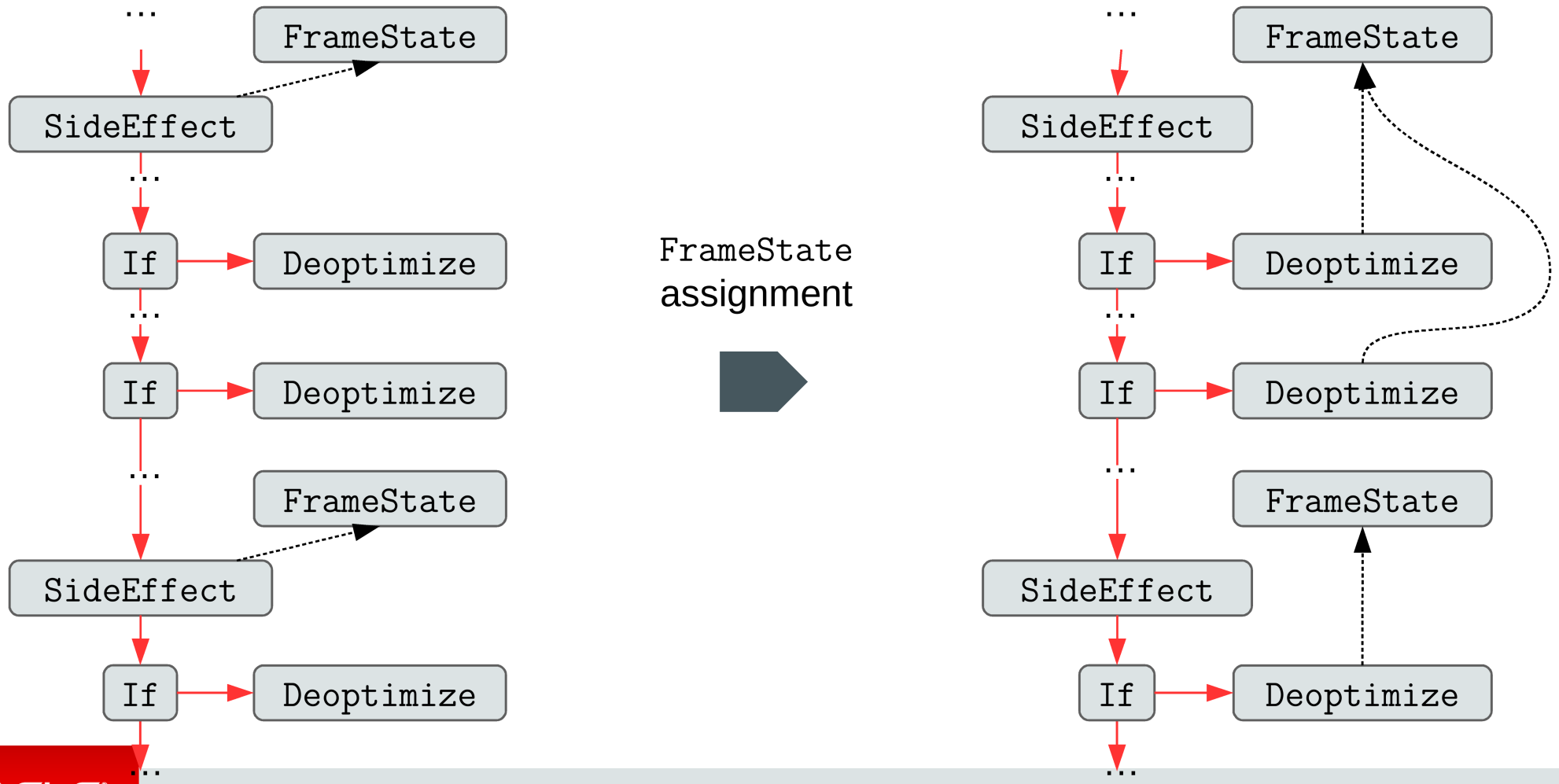



```
...
obj1.x = 1;
if (c) {
  t = obj2.y;
} else {
...
}
...
```

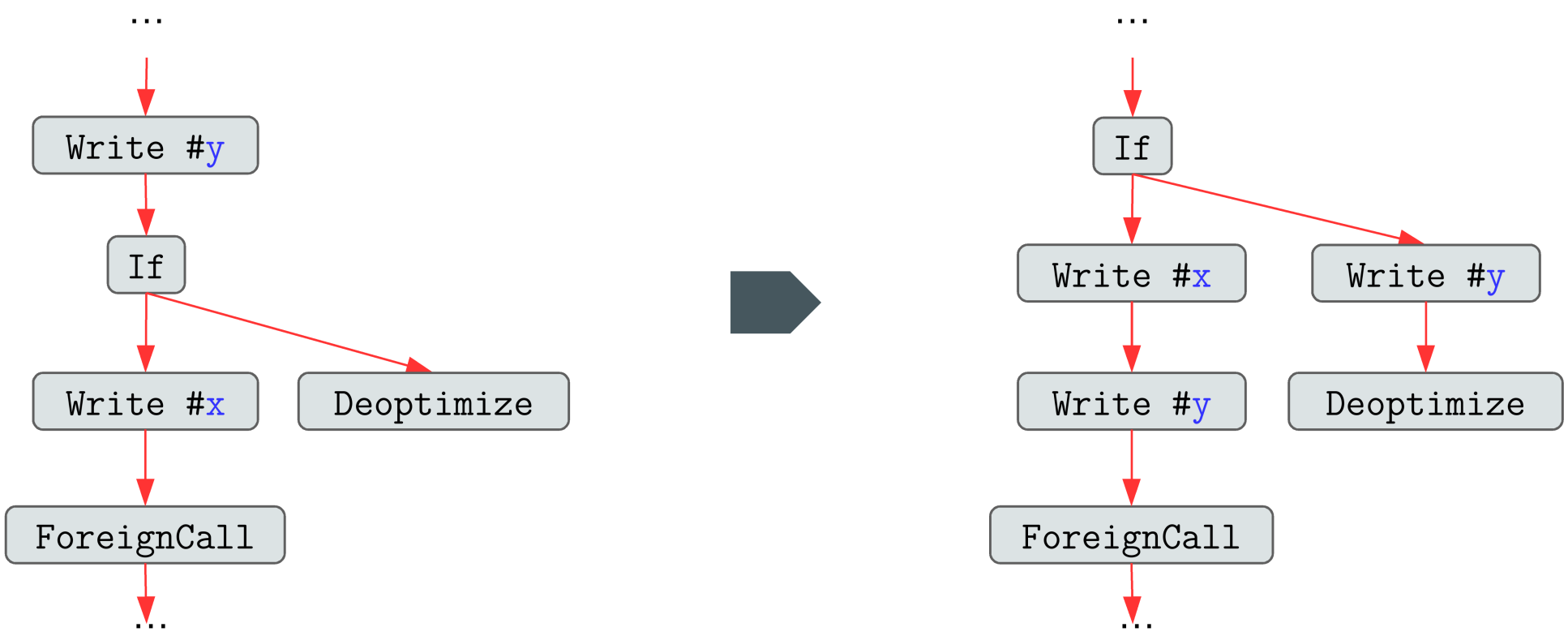
Optimization Stages: Transition



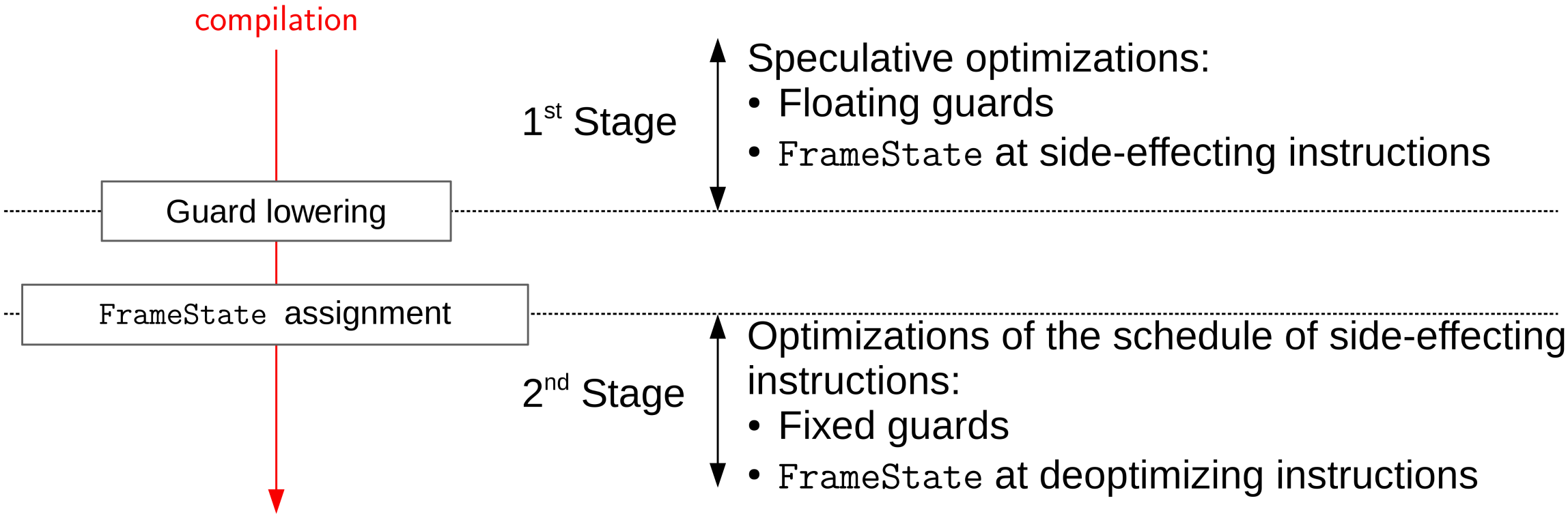
Optimization Stages: Transition



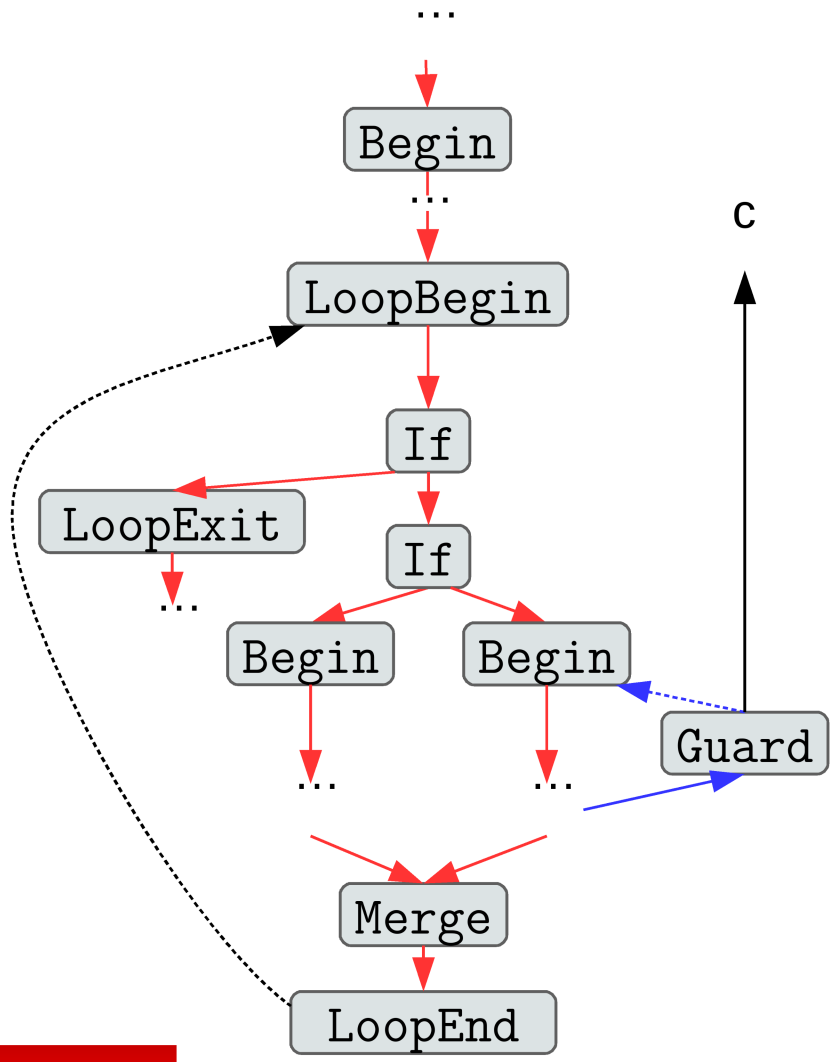
Optimization Stages: 2nd Stage



Optimization Stages

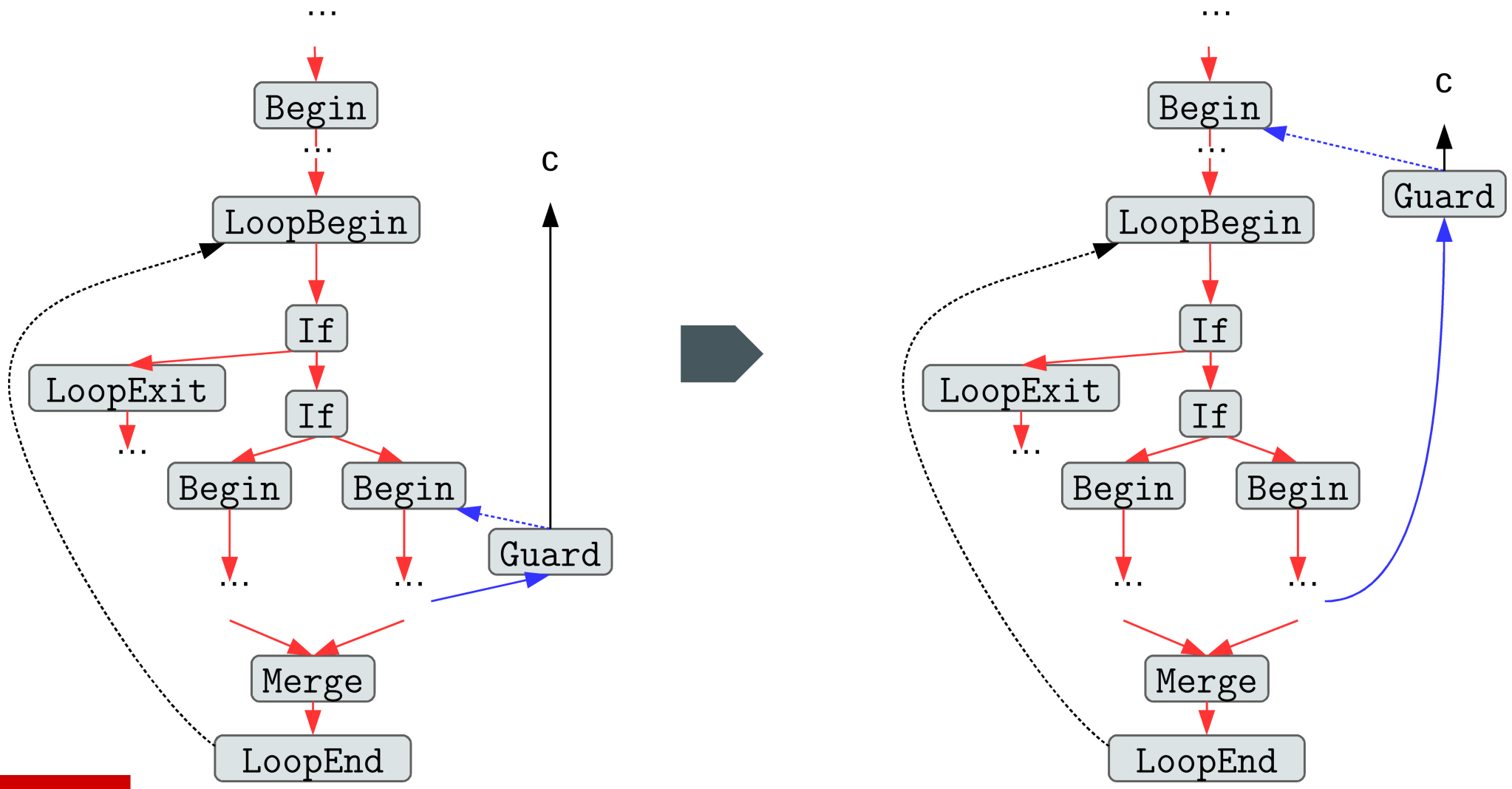


Speculative Guard Motion




```
boolean c = ...
for (...) {
  if (...) {
    guard(c);
  }
}
```

Speculative Guard Motion



Speculative Guard Motion

- Refinements:
  - Rewrite induction variable comparisons

    i < c → min(i) < c && max(i) < c
  - Processing order

    Hoisting a guard may make new code loop invariant and allow other guards to be hoisted
  - Check relative frequencies

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    i < c → min(i) < c && max(i) < c
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    Hoisting a guard may make new code loop invariant and allow other guards to be hoisted
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Speculative Guard Motion

```
for (int i = 0; i < n; i++) {
    x = …; y = …;
    if (x > 100) {
        guard(a != null);
        guard(i < a.length);
        y -= a[i];
    }
}
```

```
guard(a != null);
for (int i = 0; i < n; i++) {
    x = …; y = …;
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Speculative Guard Motion

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guard(a != null);
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for (int i = 0; i < n; i++) {
    x = …; y = …;
    if (x > 100) {
        y -= a[i];
    }
}
```

Alias analysis

```
for (int i = i0; i < a.length; ++i) {
  c[i] = a[i-1] * 2 + 1;
}
```

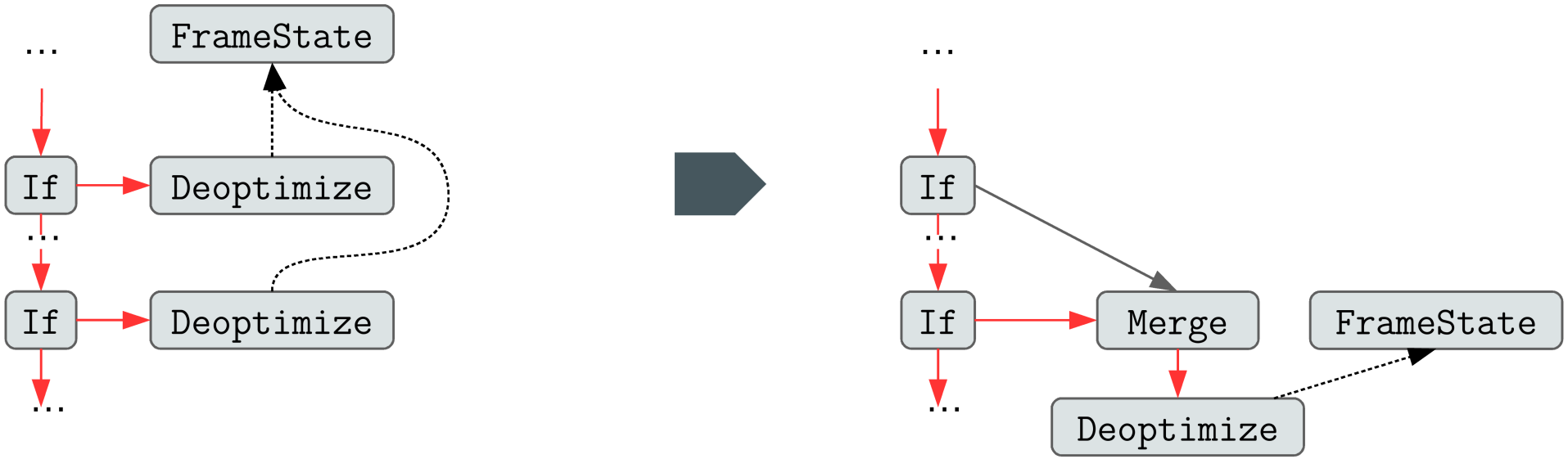
```
guard(c != a);
for (int i = i0; i < a.length; ++i) {
  c[i] = a[i-1] * 2 + 1;
}
```

Safepoint Elimination

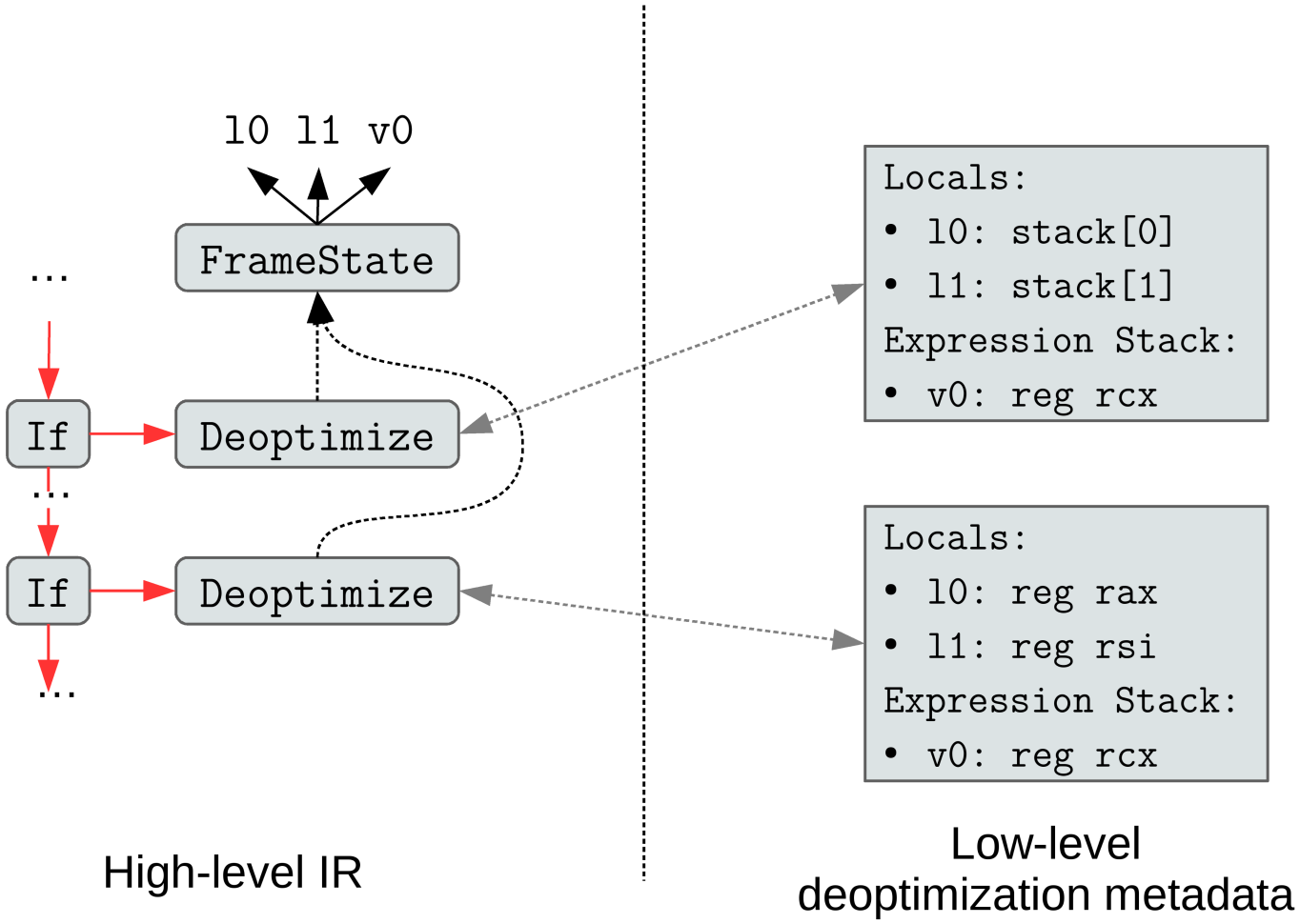
```
for (int i = 0; i < n; i+=2) {
  …
  safepoint();
}
```

```
guard(n < MAX_INTEGER);
for (int i = 0; i < n; i+=2) {
  …
}
```

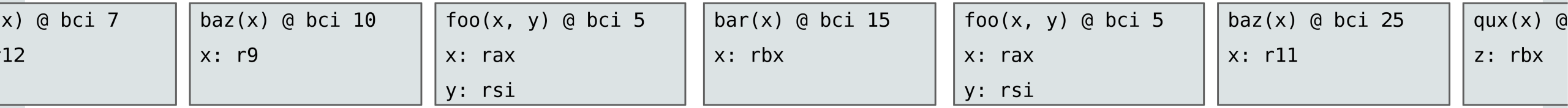
Deoptimization Grouping



Deoptimization Grouping



Debug Info Sharing



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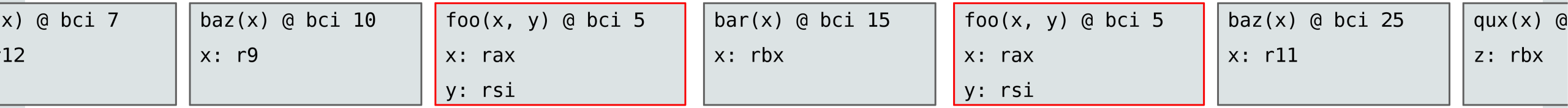

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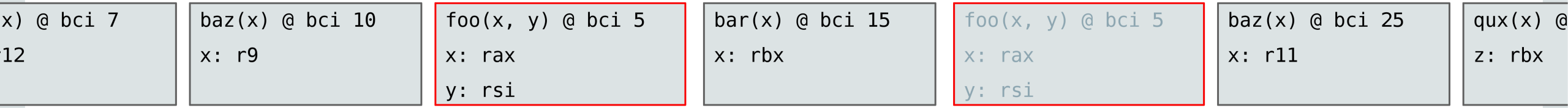

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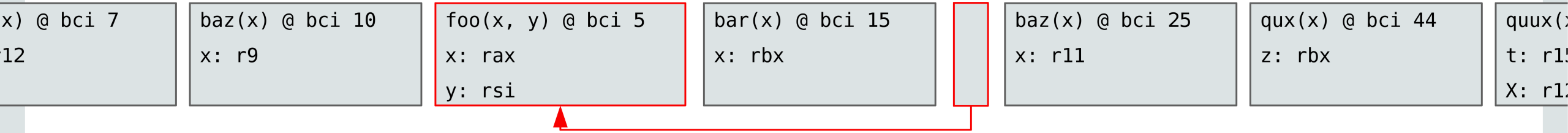

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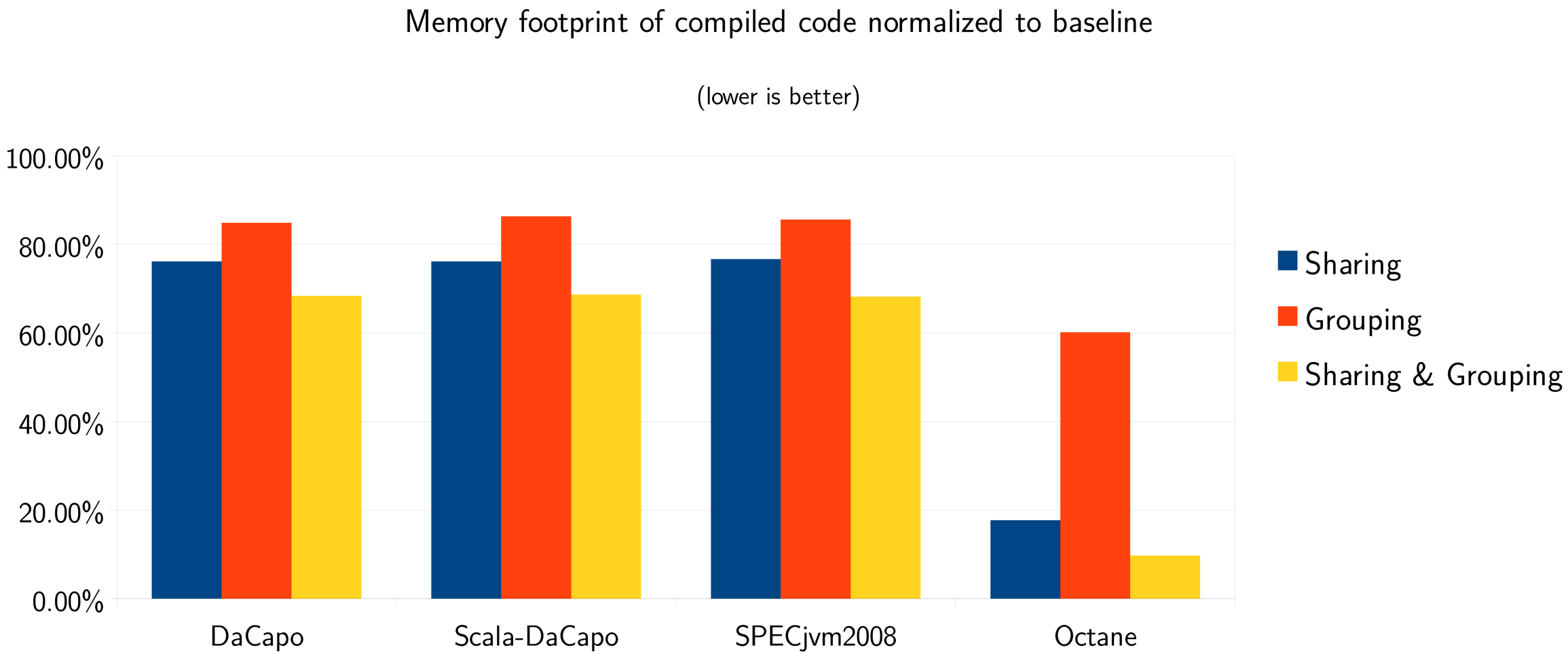

Loop Fusion

```
double[] b = new double[a.length];
for (int i = 0; i < a.length; ++i) {
  b[i] = a[i] * 2;
}
double[] c = new double[a.length];
for (int i = 0; i < a.length; ++i) {
  c[i] = b[i] + 1;
}
```

```
double[] c = new double[a.length];
for (int i = 0; i < a.length; ++i) {
  c[i] = a[i] * 2 + 1;
}
```

Effect Sinking

```
for (int i = i0; i < n; ++i) {
  this.x = this.x * 2 + 1;
}
```

```
int tx = this.x;
for (int i = i0; i < n; ++i) {
  tx = tx * 2 + 1;
}
this.x = tx;
```

Questions


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